의학박사 학위논문

Biomechanical Comparison of Three Tension Band Wiring Techniques for Transverse Fracture of Patella

–Traditional Tension Band Wiring, Tension Band Wiring using Cannulated Screws, and Tension Band Wiring using Ring Pins–

슬개골 횡골절에 시행한 세 가지 장력대 강선 고정법의 생역학적 비교
–전통적 장력대 강선 고정술, 유관나사를 이용한 장력대 강선 고정술 및 링핀을 이용한 장력대 강선 고정술–

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의학과 정형외과학 전공

이 경 학

슬개골 횡골절에 시행한 세 가지 장력대 강선 고정법의 생역학적 비교

– 전통적 장력대 강선 고정술, 유관나사를 이용한 장력대 강선 고정술 및 링핀을 이용한 장력대 강선 고정술 –

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이 논문을 의학박사 학위논문으로 제출함

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2020 년 1 월

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Abstract

Patellar fracture is common and, of them, transverse fracture is the most common. For the treatment of transverse patellar fractures, various methods are used, and studies comparing various fixation methods of patella have been published. However, there are no report comparing tension band wiring with ring pin (TBWRP) with traditional tension band wiring (TTBW) and tension band wiring with cannulated screw (TBWCS). This study aims to compare biomechanical property of these three methods.

Transverse osteotomy was made on patella sawbones to simulate transverse patellar fracture. On the upper and lower fracture plane, polyester loop was attached which was used as an anchor for biomechanical test. Fixation using TTBW, TBWRP and TBWCS was done for 16 patellae each. For 10 patellae in each group static biomechanical test was performed, and for 6 patellae in each group, dynamic test was performed. Failure was

defined as yield point or fracture gap of 2 mm. With a preload of 100N, biomechanical test was performed with 90 angle force application with the hinge of artificial distal femur. For static test, force was applied with a rate of 5mm/min, and force and displacement were measured. Dynamic biomechanical test was done with 10,000 cycles at 5 Hertz, and load was increased from preload 100N to 300 N. After completion of dynamic test, fracture gap was measured.

The load to failure for TTBW, TBWRP, and TBWCS were 438.6 ± 138.6, 422.2 ± 72.7 and 1106.8 ± 230.3, showing statistically highest failure load in TBWCS ($p < 0.01$). Mean value of fracture gap after dynamic test for TTBW, TBWRP, and TBWCS were 0.3267 ± 0.3395, 0.2938 ± 0.21648 and 0.0360 ± 0.057, showing difference between groups ($p < 0.05$)

TBWCS group showed best mechanical property in both static and dynamic test. The result of static and dynamic test was comparable in both TTBW and TBWRP group. TBWRP can be used as an alternative for TTWB.

Keywords: Fracture fixation/internal, Patella, tension band, biomechanics

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Introduction

Patella fracture is a fracture consisting 1% of all extremity fractures, and among them, transverse type (OTA/AO 34−C1) is the most common. (1, 2) The purpose of operative treatment for patellar fracture is to restore anatomical reduction of the joint surface and to make a strong enough fixation to allow early passive range of motion exercise which prevents intra and peri−articular fibrosis and helps articular cartilage healing (3−5). For this purpose, various fixation methods have been introduced (5−7).

The most common type of fixation method used for transverse patella fracture is traditional tension band wiring (TTBW) using two K−wires across the fracture site with a vertical figure of 8 pattern circlage wiring (4). However, various complications including protrusion and extrusion of the implant resulting in pain and wound problem has been reported (8), resulting in implant removal rate up to 40% (9−11).

For this reason, tension band wiring using cannulated screw (TBWCS) was introduced to overcome these complications and is substituting TTBW as a treatment of choice for transverse patellar fracture (12). The clinical result of TBWCS is generally reported to be superior to TTBW, and this result is supported by various studies reporting superior biomechanical property of TBWCS compared with TTBW (8, 13, 14). However, there is some innate problems with TBWCS including excessive bone loss, technical difficulty, fixation problem with small patella, and additional risk of fracture (5, 11), which can be a more important issue to consider in Asian population whose patella is smaller than Caucasian population (15).

To overcome these problems, tension band wiring using ring pin (TBWRP) for patellar fracture was introduced, and good clinical result with less pin migration and was reported (16, 17). Moreover, superiority of fixation utilizing ring pin is also reported for olecranon fracture for the same reason (18). However, until now, there is no biomechanical test of TBWRP for patellar fracture, and for the final confirmation of the safety of this technique, mechanical test of TBWRP is mandatory. The purpose of current study is to compare mechanical characteristics of TTBW and TBWRP, and also compare with TBWCS technique as a control.

Materials and Methods

1. Preparation of specimen

Total of 48 polyurethane foam patellae (Sawbones, Pacific Research Laboratories Inc., Vashon, WA, USA) were used for the biomechanical test. Size of 25x3mm transverse hole was generated on the central part of the patella to pass nylon band (Rib webbing, HS Korea, Seoul, Korea) which will play a role as quadriceps tendon and patellar tendon. After then, transverse fracture was made using 1mm thick manual saw on the middle one−third of the patella. Fractured patella foams were reduced and fixed with the methods described below according to their groups. (3 groups, 16 each) (Fig 1)

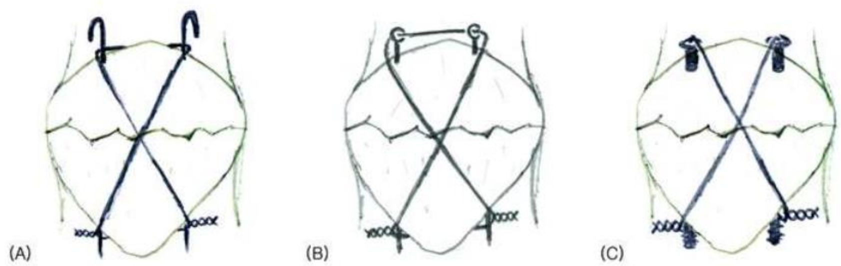

Figure 1. Fixation methods of each group. A. TTBW, B. TBWRP, C. TBWCS

1.1 TTBW group

Two 2.0 mm K−wires (Solco biomedical, Gyeonggi−do, Republic of Korea) were inserted perpendicular to the transverse axis of the patella and parallel to each other on its medial 1/3 and lateral 1/3. Through the hole generated before, two 25 cm polyester belt was passed. 18G roll wire (Solco biomedical, Gyeonggi-do, Republic of Korea) was passed around the K-wire, making vertical figure of 8 wiring, and two knots were twisted on the distal part of K-wire and tightened. Proximal part of the K-wire was bent and cut, and impacted for the complete touch with the sawbone surface, completing the TTBW fixation model.

1.2 TBWCS group

After reduction, two 1.0 mm K-wires (Solco biomedical, Gyeonggi-do, Republic of Korea) were inserted perpendicular to the transverse axis of the patella on its medial 1/3 and lateral 1/3. Using drill bit, screw holes were made, and two 4.0mm cannulated screws (Asnis III Cannulated Screw System, Stryker orthopaedics, Mahwan, NJ, USA) were inserted. Two 25 cm nylon band were passed through the hole. 18G roll wire was passed through the cannulated screw, making horizontal figure of 8 wiring, and K-wire at the distal tip of the screw were tightened, completing the TBWCS model.

1.3 TBWRP group

Surgical procedures were the same with TTBW, except using ring pin (Jaeil medical, Seoul, Korea) instead of K−wire. Roll wire was passed through the ring of the pin, and rounded making a vertical figure of 8 wiring, and tightened at the distal portion of the ring pin, completing the TBWRP model.

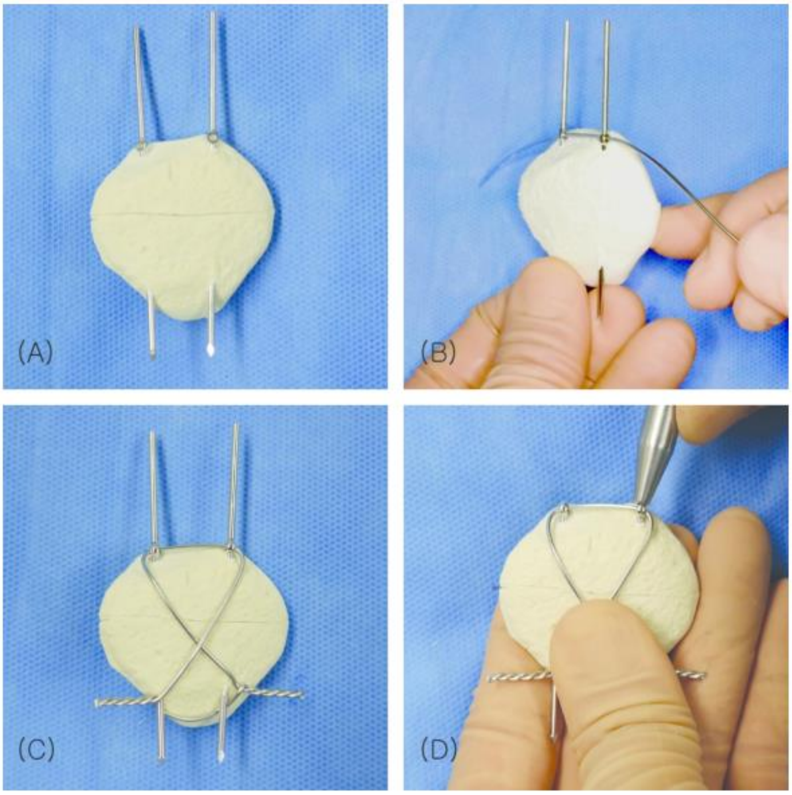

Figure 2. Preparing a specimen for TBWRP group. A. Insertion of ring pin perpendicular to the fracture site. B. Passage of K−wire through proximal ring. C. Tightening wire D. Remoing proximal remnant of ring pin

After completion of the fixation in all groups, ends of the nylon bands were sewn together to complete proximal and distal loops.

2. Specimen Mounting for Mechanical Test

Biomechanical test was performed using Instron® material testing machine E3000 (Instron Engineering Corporation, Norwood, MA, USA). Fixation board that can be fixed to the base of the Instron® with a vertical rod was designed for this study and manufactured. On the base of the fixation board, fixation device for metal cable that can attach the lower part of the polyester band was built. And on the vertical rod, a femur mounting device, where femur polyurethane foam (Sawbones, Pacific Research Laboratories Inc., Vashon, WA, USA) will be fixed to act as distal femur, and a pulley system, which will change the direction of the force generated by Instron®, were built, and metal cable was fixed to the Instron®. Patella specimen were placed over the center of femoral condyle, and polyester loops on both ends were connected to the superior and inferior cable. The angle of the polyester band was set to 90 degrees (19).

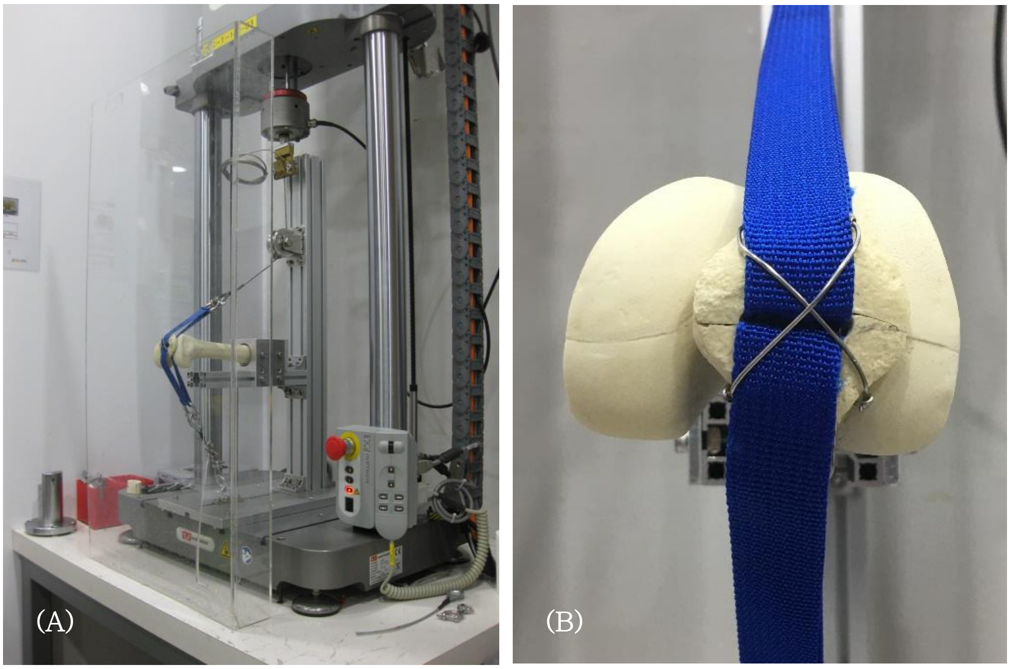

Figure 3. Specimen mounting for mechanical test. A. Overall appearance of mechanical test. Force was generated by upper part of Instron®, and force was transferred to the patella via cable, pulley, and polyester band. B. Two polyester bands acting one as patellar tendon and the other as quadriceps tendon.

3. Biomechanical testing

3.1 Static test

Ten specimens of each fixation groups were used for static test. After mounting, preload of 100 N was applied, and tensile load was applied with the speed of 5 N/min. Definition of failure was when there is a failure point on a stress−strain curve, or when fracture gap of 2mm of was observed, which was measured at the medial or lateral edge of the patella. Force at the failure point was documented. Fracture gap was primarily observed with a ruler attached to the femoral condyle using magnification device, and for final decision of failure, digital ruler (Digital ABS AOS Caliper® 0−150mm, Digimatic, Rod, Germany, Neuss) was used. During and after the test, mode of failure was observed.

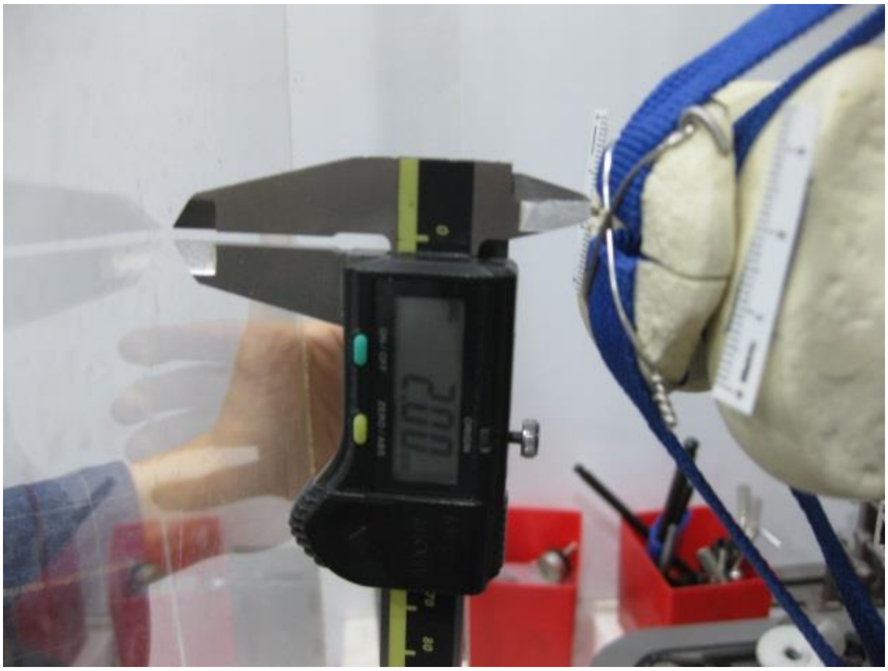

Figure 4. Measurement of fracture gap. Initially, fracture gap was observed by the ruler attached to the femoral condyle with magnification device, and digital ruler was used for final confirmation of fracture gap of 2mm, and the force at this point were recorded.

3.2 Dynamic test

Six specimens of each fixation groups were used for dynamic test. After mounting, preload of 100N was applied, and force from 100N to 300N was applied with the frequency of 5Hz. After completion of 10,000 cycles, fracture gap was measured after retrieval, and the medial and lateral fracture gap was measured using TREZEK (VMQ100PK, China).

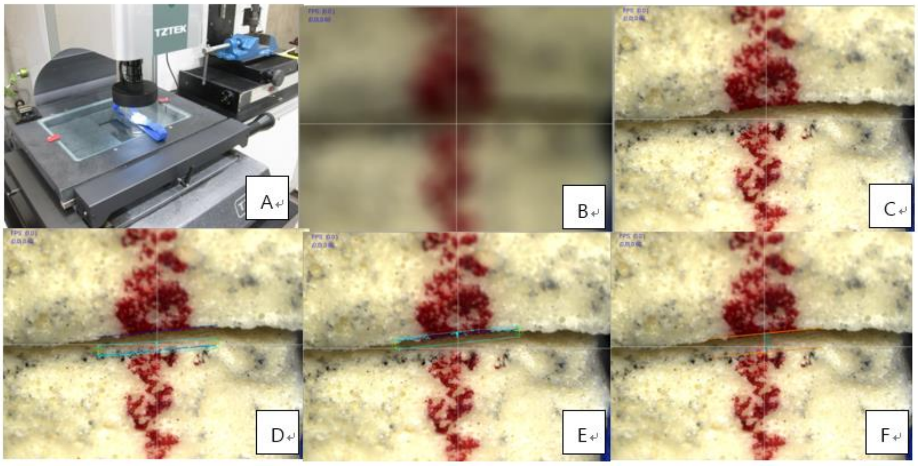

Figure 5. Measurement of fracture gap using Trezek. A. Mounting the specimen after dynamic test B. Before focusing on. C. After focusing on. D. Marking fracture line in the inferior part of patella. E. Marking fracture line on the superior part of patella. F. Fracture gap measured based on the line generated in Fig 4D and Fig 4E.

4. Statistical analysis

Statistical analysis was performed using SPSS Statistics version 23.0 (International Business Machines Corporation, NY, USA). For static test, one-way ANOVA test was used, and for dynamic test, Kruskal-Wallis test was used to compare the mean value.

Results

1. Static test

All specimen except one specimen in TBWCS group failed due to a fracture gap of 2mm. One specimen in TBWCS failed due to sudden breakage which showed failure point in stress-strain curve. Force at the failure point was 438.6 ± 138.6, 422.2 ± 72.7, and 1106.8 ± 230.3 for TTBW, TBWRP, and TBWCS group. TBWCS showed statistically significant difference compared to TTBW and TBWRP ($p < 0.01$) and there was no difference between TTBW and TBWRP (Table 1)

Mode of failure showed difference between TTBW, TBWRP and TBWCS. In both TTBW and TBWRP, slippage of distal portion of pin accompanied with loosening of the wire knot was the mode of failure. However, in TBWCS group, proximal head impaction was the mode of failure except for specimen 4, which exhibited saw bone abrupt breakage.

Table 1. Results of static test

Serial No	TTBW	TBWRP	TBWCS
1	520	429	983
2	618	349	920
3	620	368	1277
4	312	589	625
5	300	444	1294
6	443	340	939
7	460	460	1245
8	245	409	1218
9	552	452	1217
10	316	382	1350
Mean ± SD	438.6 ± 138.6	422.2 ± 72.7	1106.6±230.3

2. Dynamic test

The mean fracture gap after completion of dynamic test were 0.3267 ± 0.3395, 0.2938 ± 0.21648, and 0.05692 ± 0.25792 for TTBW, TBWRP, and TBWCS. There was no failure in all groups, but the mean value showed statistical difference between groups ($p < 0.05$) with no difference in post-Hoc test (Table 2)

Table 2. Fracture gap of each group after completion of dynamic test (mm)

Serial No.	TTBW	TBWRP	TBWCS
1	0.8746	0.6158	0
2	0	0.323	0
3	0.5204	0.1621	0
4	0.1795	0.1567	0.1261
5	0.3854	0.04025	0
6	0	0.46515	0.0900
Mean ± SD	0.3267 ± 0.3395	0.2938 ±0.21648	0.05692 ±0.25792

Discussion

This study is the first biomechanical test comparing TBWRP with TTBW and TBWCS. In static test, failure strength of TBWRP was lower than TBWCS and similar to TTBW. In dynamic test, there were no failures, and difference in fracture gap was shown but not confirmed between groups. Overall, TBWRP showed similar biomechanical property with TTBW.

Utilizing patellar sawbone for the assessment of fixation strength is a common method of experiment. Using cadaver may be considered as an optimal method, but most of the cadavers are in old age, which is different from the usual age distribution of patellar fracture which is 30~60 years old (1, 2), and the result utilizing cadaver is known to make inconsistent result due to the difference in sex, size, age, and severity of osteoporosis (8). The loading angle 90 degree was chosen to simulate the load applied in a stand to sit motion just prior to sitting, which high flexion activity is an important part of daily activities in Asian population (20), and also to compare with the studies performed with 60 degrees (8, 21). This angle was known to produce maximal strain on the patella while weight bearing (22, 23), which angle is also utilized in previous studies.

(13, 24, 25), Fracture gap of 2mm was defined as failure. This criterion was chosen because a gap of larger than 2mm is known to prohibit fracture healing (26), and believed to increase the risk of developing post-operative osteoarthritis and poor outcome (14, 27, 28). For dynamic test, maximum of 300N was applied to the construct, which is the force known to be the force needed to make full extension against gravity in daily activity (14, 24).

Previous studies reported higher failure load in TBWCS compared to TTBW for transverse patellar fracture which is in accordance with this study. (8, 13, 14). However, compared to the study by Wild et al. (8) the mean value is different in this study, which Wild et al. reported failure load of TBWCS to be 1.6 times higher than TTBW, but the result of this study is about 2.5 times higher in TTBCS group. This is because of the difference in the definition of failure and the different angle of the stress applied to the patella. However, statistically significant difference in failure load implies that TBWCS has higher fixation strength regardless of the definition of failure and the direction of force.

However, superior biomechanical static strength does not always guarantee superior clinical result. Hoshino et al. (11)

studied 448 patella fracture patients and reported that failure rate in TBWCS group was 7.5%, which was higher than TTBW of 3.5%. Moreover, in TBWCS group in our study, there was a fracture of sawbone before reaching the fracture gap of 2mm, which is defined as failure, and similar phenomenon was also reported in another biomechanical study by Baydar et al (29). This can be explained by higher risk of fracture due to excessive bone loss which is suggested to be a concern of TBWCS by previous reports (14, 22). Especially this can be a great problem for Asian, children, or female patients whose patella is small (15). Moreover, in senile patient whose strength of patella is weak due to osteoporosis, firm fixation with screw cannot be achieved or the excessively stiff fixation construct can lead to bone fracture, which was also shown in previous study (5).

TBWRP group showed comparable fixation strength in static test compared to TTBW group, but recent studies indicate superior clinical results in TBWRP (16, 17, 30). Kim et al (16) reported TBWRP to have 100% union rate with 0% pin migration with pin removal rate of 8.3% which is lower than the previously reported outcome of TTBW. Kyung et al. (17) also reported 100% union, 4.2 % migration, and 8.7% pin removal rate which was shown to have superior clinical result compared with TTWB technique. Moreover, technique of TBWRP is relatively simpler than TTBW, which requires no additional bending of K-wire for the completion of making a construct.

Mode of failure has some implications to improve fixation strength. Slippage at distal portion was the mode of failure for both TTBW and TBWRP, which is accordance with the previous study (8). As such, bending the wire at distal portion will improve failure load for these methods. Additionally, to improve fixation strength of the construct, utilizing thicker wire, using additional K-wire/ring pin (31), or inserting K-wire with angulation can improve fixation strength of the construct (32). And as the wire twists were loosened in TTBW and TBWRP group, circlage handling should be done with precaution (33). Proximal head subsidence was the mode of failure for TBWCS, which is in accordance with another study (34). As such, utilizing washer along with the screw will improve failure load for TBWCS technique, which role is proved in other studies (35, 36).

The result of dynamic test showed difference between TBWRP and TBWCS group. However, what is more important, there was no failure in all three methods after completion of

10,000 times of cyclic load. This finding implies that with a force of 300N, which is considered to be the force applied to patella in daily activities (14, 24), there will be no difference in failure rate among the three methods. This finding is in accordance with the study by Thelen et al. (21) which showed no occurrence of failure in TTBW and TBWCS group with same force applied as this study with 60 degrees of flexion angle.

There are some limitations of this study needs to be mentioned. First, as the technique of TBWCS is recommended to position the thread into the cancellous bone, the result of static and dynamic test shown here may be an exaggerated value as the saw bone patella is composed purely of cortical portion. However, the result of cadaveric study comparing TTBW and TBWCS also reports higher load to failure in TBWCS group, which is in accordance with this study (29). Second, interference of soft tissue cannot be put into consideration which is an innate limitation of mechanical test with sawbone. However, soft tissue issue can be another confounding factor of cadaver study which cannot be controlled uniformly. Third, the pull out of K-wire or ring pin, which is the most important clinically proven difference between TTBW and TBWRP, could not be reproduced with this experimental setting.

We are considering to design a new experimental study to prove this phenomenon in the future.

Conclusion

TBWRP showed compatible mechanical characteristics with TTWB, but considering its clinically proven advantage, TBWRP may be a good alternative for TTBW. TBWCS showed better mechanical characteristics compared with TTBW and TBWRP, but as the clinical superiority is still in doubt with its innate risk, TBWRP can be a good alternative treatment modality for transverse patellar fracture.

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초록

슬개골 횡골절에 시행한 세 가지 장력대 강선 고정법의 생역학적 비교
: 전통적 장력대 강선 고정술, 유관나사를 이용한 장력대 강선 고정술 및 링핀을 이용한 장력대 강선 고정술

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학과 및 전공 의학과: 정형외과학

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슬개골 골절은 비교적 한하게 발생하는 골절이며, 그 중 횡형 슬개골 골절이 가장 많이 발생한다. 슬개골 골절에 대한 내고정을 위하여 여러가지 방법이 사용되고 있으며, 이러한 고정법들의 역학적 강도를 비교하는 연구는 그동안 다양하게 보고되어 왔다. 그러나 링핀을 이용한 장력대 강선 고정술의 정적 및 동적 강도를 고식적 장력대강선 고정술 및 유관나사를 이용한 장력대 강선 고정술과 비교한 연구는 없었다. 본 연구에서는 이러한 세가지 고정 방법의 역학적 특성을 연구하고자 한다.

슬개골의 횡골절을 재현하기 위하여 인조골에 횡형 절골술을 실시하였다. 골절면의 근위부 및 원위부에 역학적 실험을 위하여 연결할 수 있는 폴리에스터 끈을 설치하였다. 상기 세가지 방법으로 각각

16표본의 슬개골을 고정하였으며, 그 중 10개의 표본은 정적 실험을 위하여 사용하였으며, 6개의 표본은 동적 실험을 위하여 사용하였다. 고정 실패는 항복점이 관찰이 되거나 골절 간극이 2mm 이상이 되는 것으로 정의 하였다. 대퇴골 모형의 원위부에 모형을 안착시키고 90도의 각도로 100 뉴턴의 전부하를 가한 후 실험을 실시하였다. 정적 실험에서는 분당 5mm 의 속도로 힘을 가하였으며, 고정 실패시의 힘을 기록하였다. 동적 실험에서는 상기 조건과 동일하게 설치한 후 초당 5회로 100뉴턴에서 300뉴턴의 힘을 주었으며, 총 10,000 회의 주기로 실험을 실시하였다. 동적 실험 종료 이후 골절 간극을 측정하였다.

정적 실험의 결과 고정 실패시 힘의 평균은 세가지 방법에서 각각 438.6 ± 138.6, 422.2 ± 72.7, 1106.8 ± 230.3 로 측정되었으며, 유관나사를 이용한 방법이 유의하게 높은 힘을 나타내었다 ($p < 0.01$). 동적 실험 이후의 골절 간격의 평균은 각각 0.3267 ± 0.3395, 0.2938 ± 0.21648, 0.0360 ± 0.057 이었다 ($p <0.05$)

유관나사를 이용한 슬개골 횡골절의 고정이 가장 우수한 역학적 강도를 나타내었으나, 세 고정법 모두 동적 검사상으로 일상 생활 정도의 힘은 충분히 버틸 수 있는 것이 확인되었다. 링핀을 이용한 고정술이 전통적인 고정술과 역학적 차이가 없음을 고려할 때 이를 대체할 수 있는 방법으로 판단된다.

주요어: 슬개골 골절, 골절 고정, 정적 실험, 동적 실험
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